Chapter 6

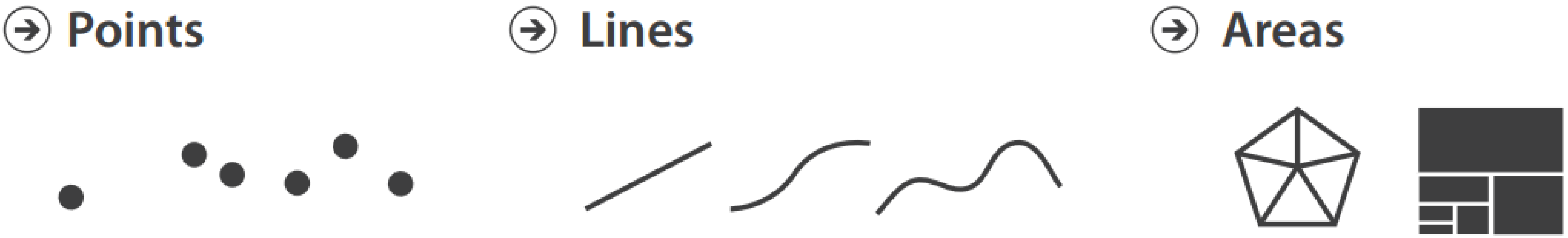
Marks and Channels

The Big Picture

- Marks
  - Basic graphical elements in an image
- Channels
  - Visual channels to control the appearance of marks
- Learning to reason about marks and channels gives you the building blocks for analyzing visual encoding
  - Orthogonal combination of
    - Marks
    - Channels

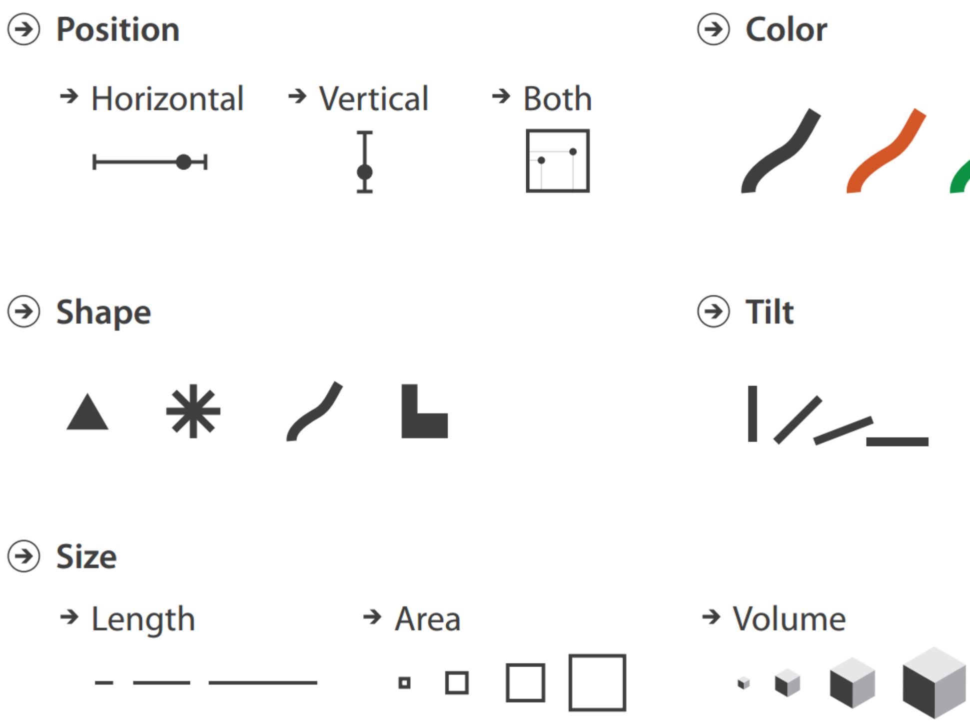
Defining Marks and Channels
Marks

- A basic graphical element in an image
  - geometric primitive objects
  - Point (0D), line (1D), area (2D)
  - Volume (3D) – not frequently used

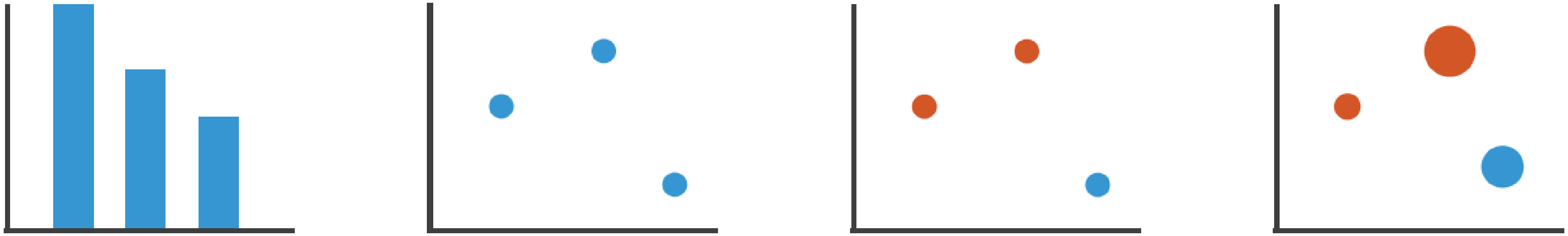


Defining Marks and Channels Visual channels

- **Control the appearance of marks**
  - Independent of the dimensionality of the geometric primitive



Defining Marks and Channels An Example



A progression of chart types.

(a) Bar charts encode two attributes using a line mark with the vertical spatial position channel for the quantitative attribute, and horizontal spatial position channel for the categorical attribute.

(b) Scatterplots encode two quantitative attributes using point marks and both vertical and horizontal spatial position.

(c) A third categorical attribute is encoded by adding color to the scatterplot.

(d) Adding the visual channel of size encodes a fourth quantitative attribute as well. (Munzner 97)

Defining Marks and Channels An Example

- **In Previous example, each attribute is encoded with a single channel**
  - Attributes for x, y axis, categorical attribute, quantitative attribute
- **Multiple channels can be combined to redundantly encode the same attribute**
  - Limitation
    - More channels are used up so that not as many attributes can be encoded in total
  - Benefits
    - The attributes that are shown will be very easily perceived

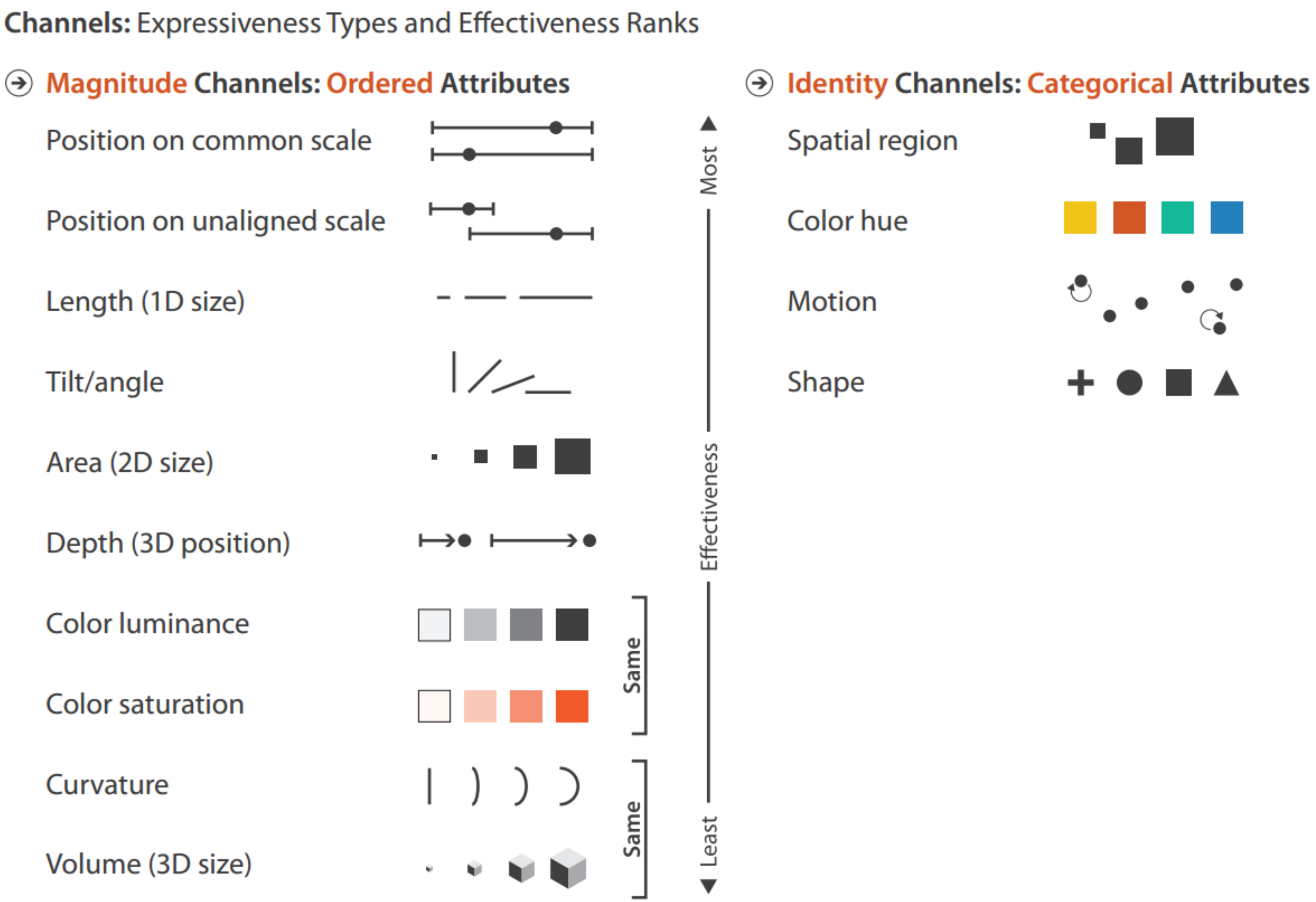
Defining Marks and Channels Some remarks

- **Area mark**
  - Typically are not size coded or shape coded
  - An area mark has both dimensions of its size constrained intrinsically as part of its shape
- **Link mark**
  - Encodes a quantitative attribute using length in one direction can be size coded in the other dim
- **Point mark**
  - Can be size coded and shape coded

Defining Marks and Channels Channel Types

- Two fundamentally different kinds of sensory modalities
  - Identity channel
    - Good for categorical data
    - *What* something is or *where* it is
      - Shape, color, motion
      - Position
  - Magnitude channel
    - Good for ordered data
    - *How much* of something there is
      - Size: Line length - how much longer is this line than that line
      - Luminance: how much darker one mark is than another
      - Angle/tilt

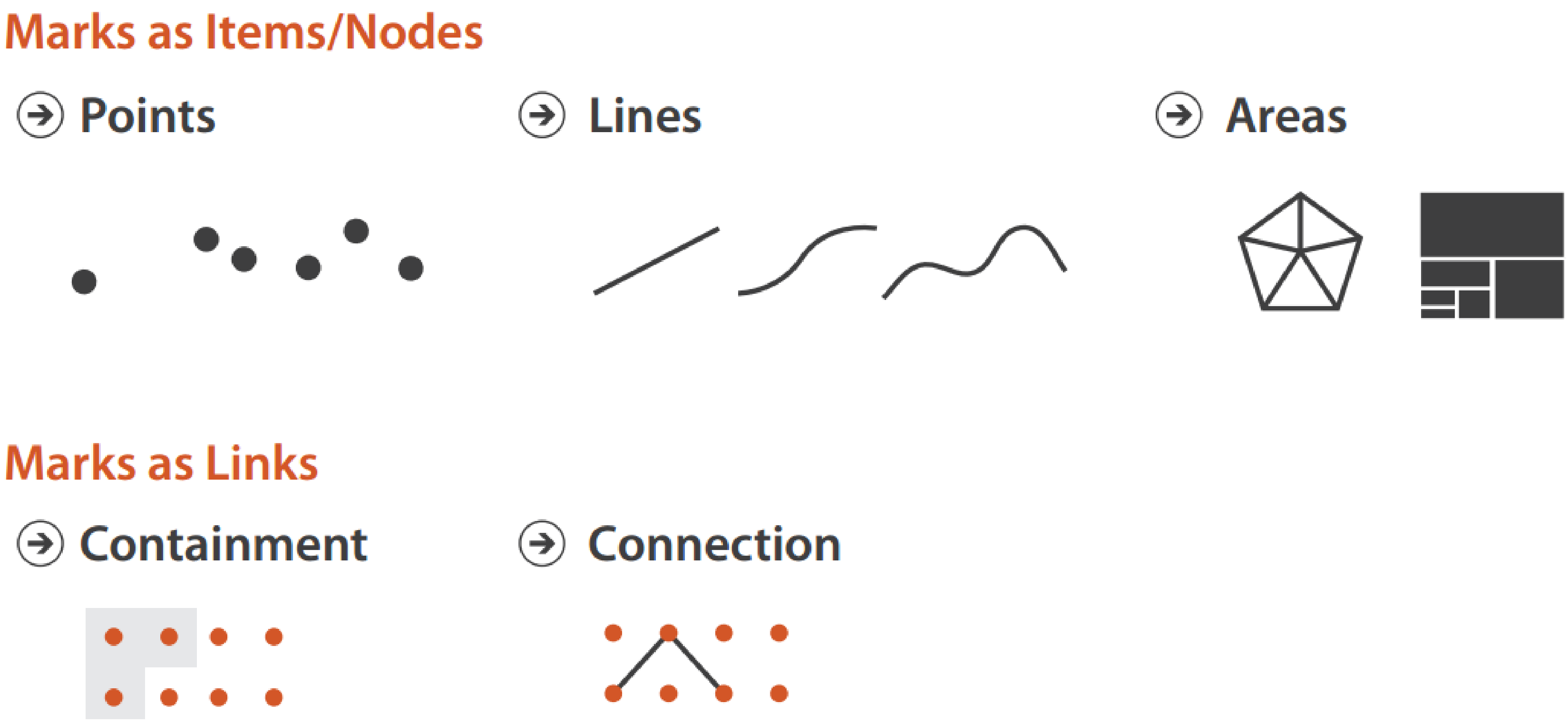
Defining Marks and Channels
Channel types



Defining Marks and Channels
Mark Types

- For table dataset
  - A mark always represents an item
- For network dataset
  - A mark can represent an item (node) or a link
  - Link mark represents relationship between items
- Link marks
  - Connection mark
    - Shows a pairwise relationship between two items using a line
  - Containment mark
    - Shows hierarchical relationship using areas

Defining Marks and Channels
Mark Types



Marks can represent individual items, or links between them (Munzner 100)

Using Marks and Channels

- **All channels are not equal**
  - **Same data attribute encoded with two different visual channels will result in different information perceived**
- **The use of marks and channels should be guided by the principles of expressiveness and effectiveness**
  - **These ideas can be combined to create a ranking of channels according to the data type that is being encoded**
    - **Identify the most important attributes**
    - **Ensure that they are encoded with the highest ranked channels**

Using Marks and Channels Expressiveness and Effectiveness

- **Expressiveness principle**
  - The visual encoding should express all of, and only, the information in the dataset attribute
  - Data attribute classification meets the split of channel types
    - Identity channel for categorical data
    - Magnitude channel for ordered data (ordinal, quantitative)
- **Effectiveness**
  - Importance of the attribute should match the salience of the channel
    - The most important attributes should be encoded with the most effective channels

Using Marks and Channels
Channel Rankings

- **Magnitude channels in ranking**
  - Aligned spatial position
  - Unaligned spatial position
  - Length
  - Angle
  - Area
  - Depth
  - Luminance, saturation
  - Curvature, volume

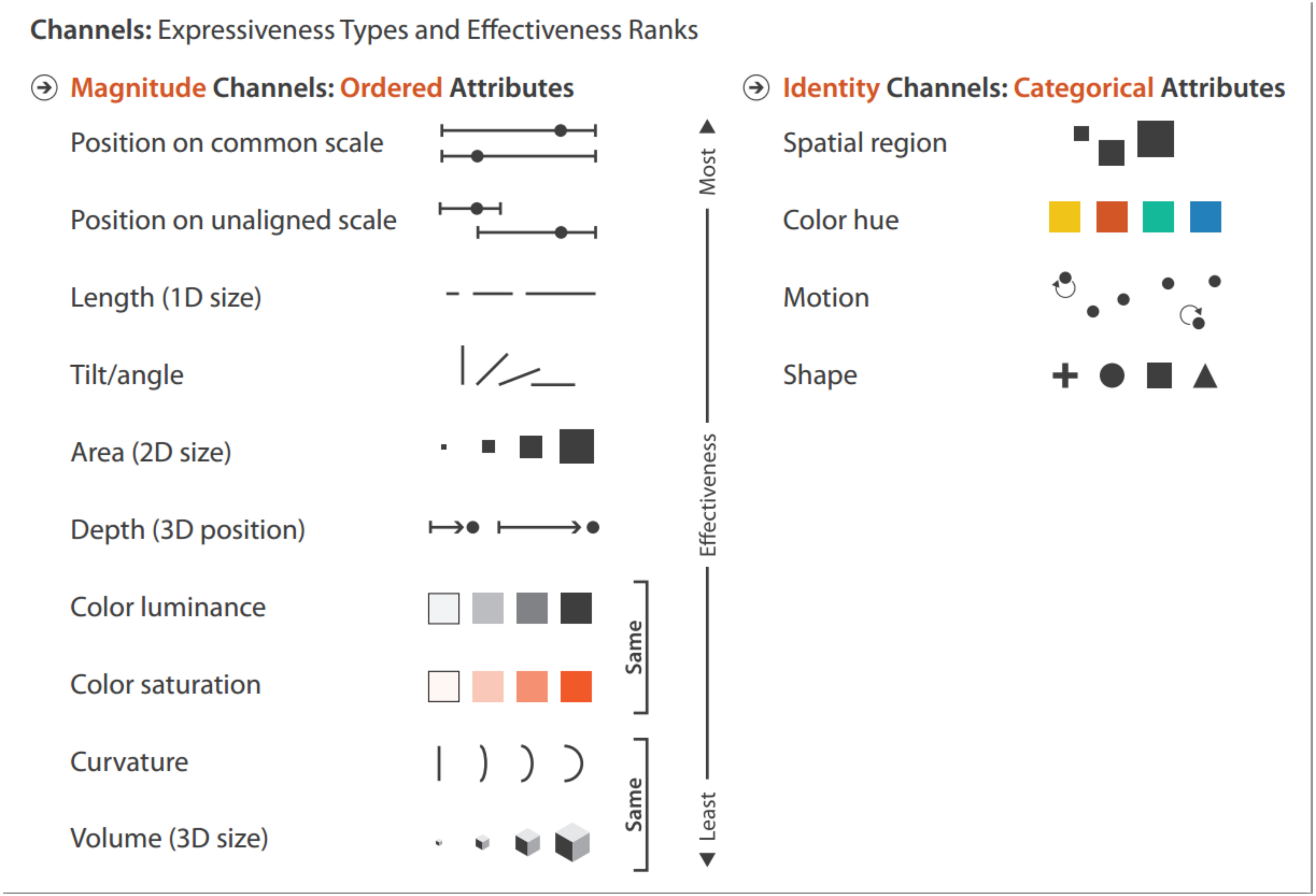
Using Marks and Channels
Channel Rankings

- **Identity channels in ranking**
  - Spatial region
  - Color hue
  - Motion
  - Shape

Using Marks and Channels Channel Rankings

- Both have channels related to spatial position at the top
  - Aligned and unaligned spatial position
  - Spatial region
- Spatial channels are the only ones that appear on both lists
- The choice of which attributes to encode with position is the most central choice in visual encoding

Using Marks and Channels
Channel Rankings



Channel Effectiveness

- **To analyze the visual encoding possibilities we need to understand the characteristics of these visual channel, because many questions remain unanswered**
  - How are these rankings justified?
  - Why did the designer decide to use those particular visual channels?
  - How many more visual channels are there?
  - What kinds of information and how much information can each channel encode?
  - Why are some channels better than others?
  - Can all of the channels be used independently or do they interfere with each other?

Channel Effectiveness Accuracy

- The obvious way to quantify effectiveness is accuracy
  - How close is human perceptual judgement to some objective measurement of the stimulus?
  - Some answers from psychophysics using systematic measurement of human perception
- Human perceive different visual channels with different levels of accuracy
  - Responses to the sensory experience of magnitude are characterized by power laws
    - Exponent depends on the sensory modality

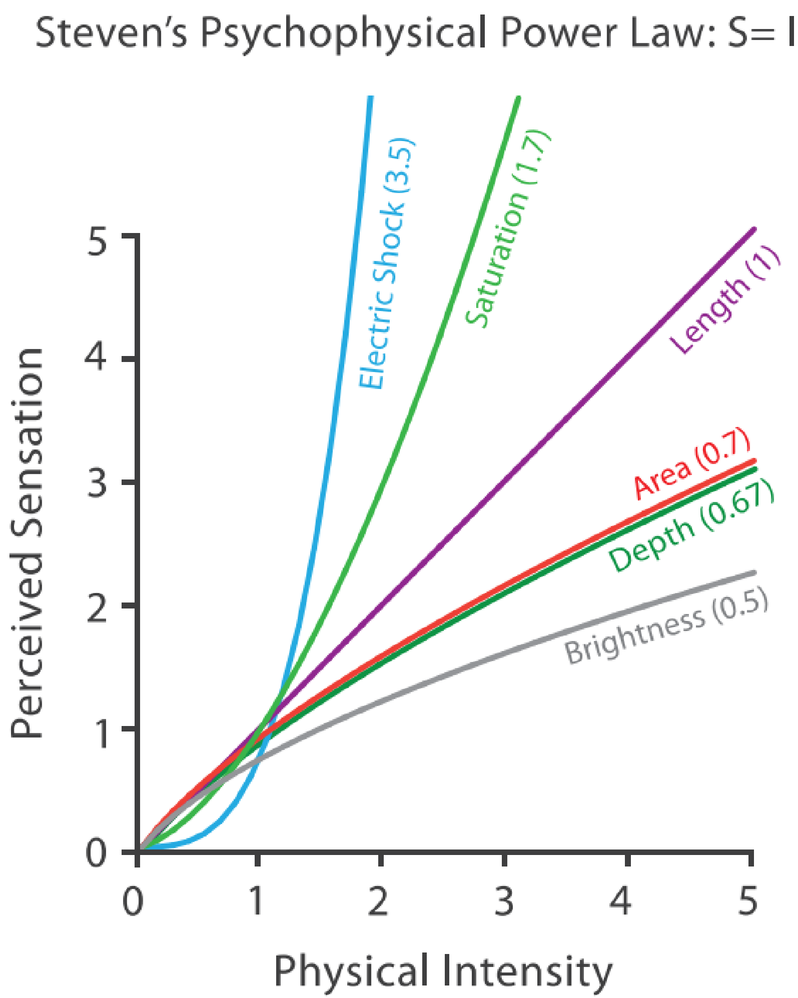
Channel Effectiveness Accuracy

- **Power law**

$$S = I^n$$

  - S: perceived sensation, I: physical intensity
  - N: ranges from sublinear 0.5 for brightness to the superlinear 3.5 for electric current
    - Sublinear: compressed, so doubling the physical brightness results in a perception that is considerably less than twice as bright
    - Superlinear: magnified, doubling the amount of electric current results in a sensation that is much more than twice as great

Channel Effectiveness Accuracy (Cont.)

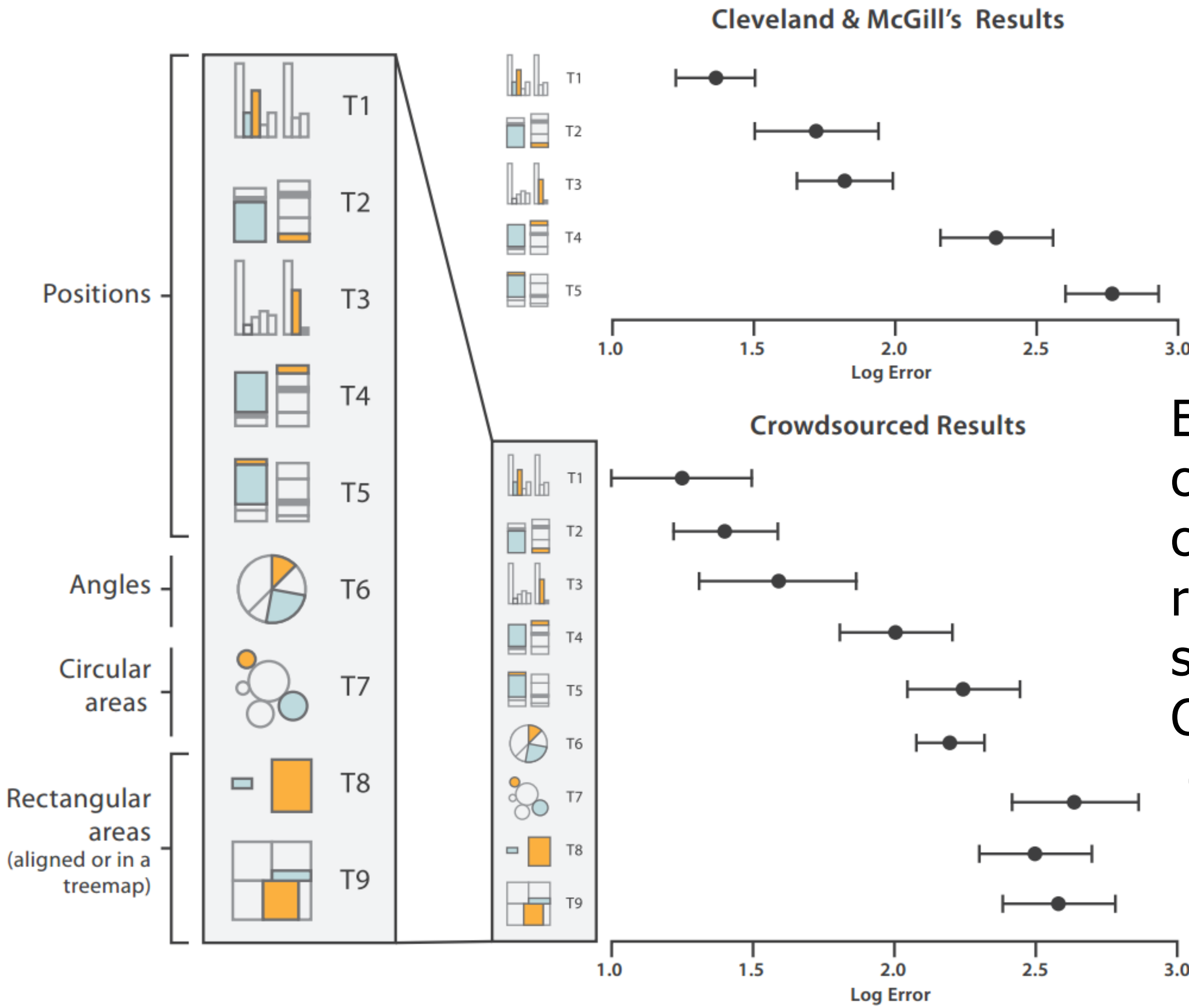


Some sensations are perceptually magnified compared with their objective intensity (when n > 1) and some compressed (when n < 1). Length perception is completely accurate, whereas area is compressed and saturation is magnified.
(Munzner 104)

Channel Effectiveness Accuracy

- **Another set of answers**
  - Come from controlled experiments that directly map human response to visually encoded abstract information, giving us explicit rankings of perceptual accuracy for each channel type
  - Cleveland and McGill's experiment
    - Aligned position against a common scale
    - Unaligned position against an identical scale
    - Length
    - Angle
    - Area
    - Volume, curvature luminance

Channel Effectiveness Error rates across visual channels



Error rates across visual channels, with recent crowdsourced results replicating and extending seminal work from Cleveland and McGill (Munzner 105)

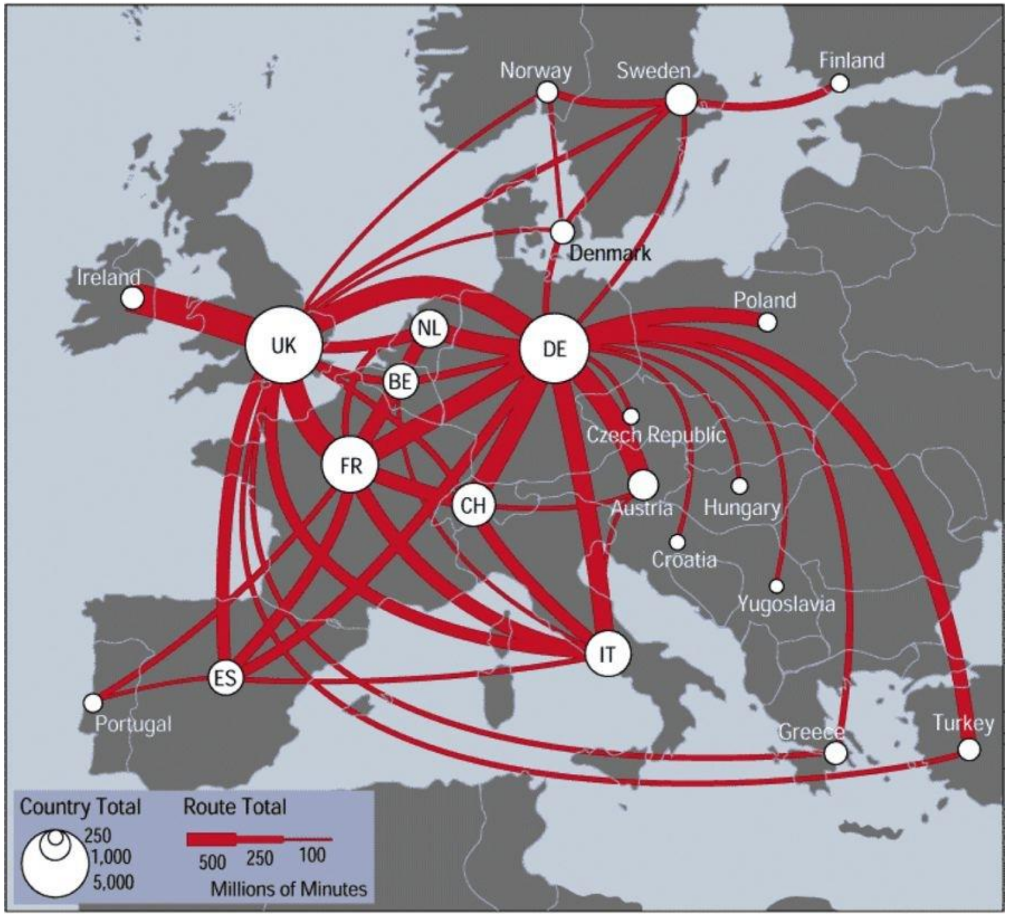
Channel Effectiveness Discriminability

- **The question of discriminability**
  - **If you encode data using a particular visual channel, are the differences between items perceptible to the human as intended?**
- **The characterization of visual channel**
  - **Should quantify the number of bins that are available for use within a visual channel, where each bin is a distinguishable step or level from the other**
- **Some channels have a very limited number of bins**
  - **Line width**

Channel Effectiveness Discriminability

- Line width
  - Changing the line width only works for a fairly small number of steps
    - Can work very well to show three or four different values for a attribute, but it would be a poor choice for dozens or hundreds of values
  - Matching for the ranges
    - The number of different values that need to be shown for the attribute must NOT be greater than the number of bins available for the visual channel used to encode it
    - If these do not match
      - Explicitly aggregate the attribute into meaningful bins, or
      - Use a different channel

Channel Effectiveness
Example of Discriminability



Linewidth has a limited number of discriminable bins.

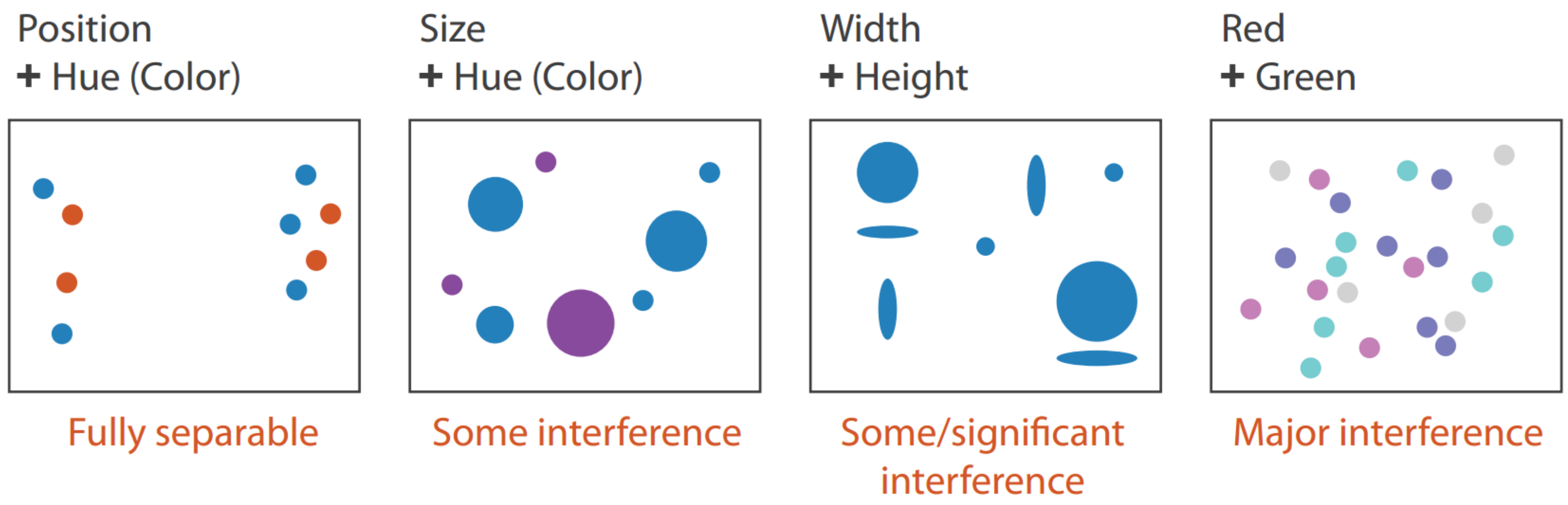
Channel Effectiveness Separability

- **Some channels have dependencies and interactions with others**
  - **Pairs of visual channels fall along a continuum from fully separable to intrinsically integral**
    - **Separable channels: visual encoding is easy**
    - **Integral channels: hard**
- **Integrality vs. separability is not good or bad**
  - **The important idea is to match the characteristics of the channels to the information that is encoded**

Channel Effectiveness Separability

- **An example**
  - **Position and color hue: completely separable**
    - **Can easily see that the points fall into two categories for spatial position, left and right**
    - **Can also separately attend to their hue and distinguish the red from the blue**
  - **Size is not fully separable from color hue**
    - **Can easily distinguish the large half from the small half**
    - **Within the small half, distinguishing the two colors is much more difficult**

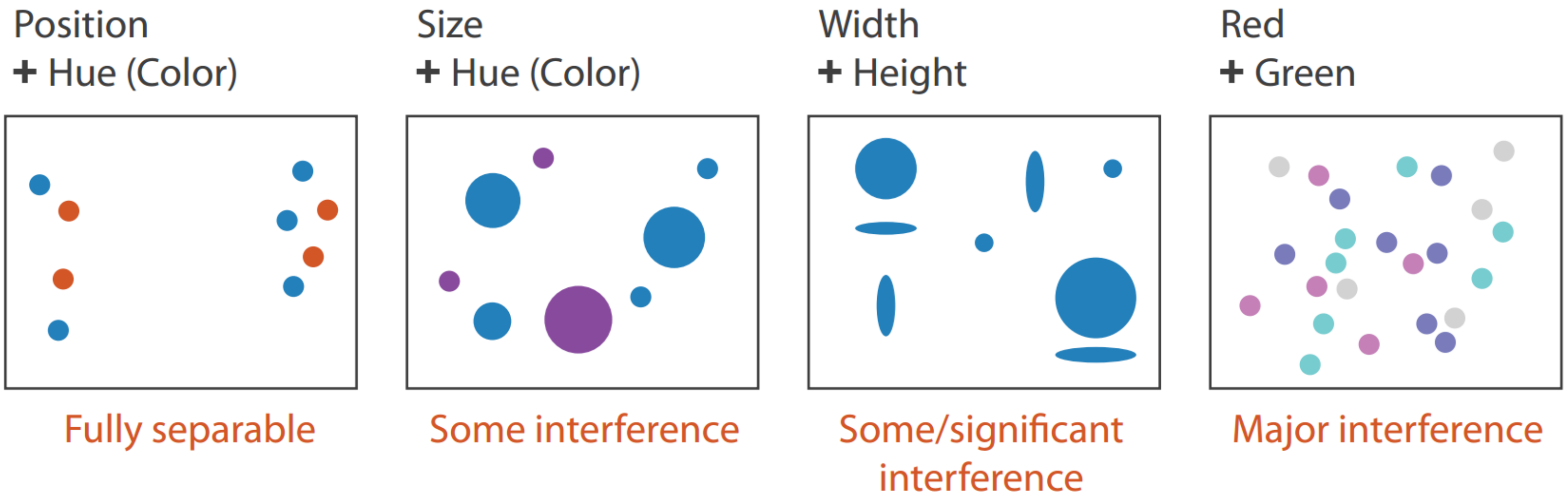
Channel Effectiveness
Separability



Channel Effectiveness Separability

- Vertical height and horizontal width interfere each other
  - What we directly perceive is the planar size of circles
  - Cannot easily distinguish groupings of wide from narrow, and short from tall
  - The most obvious perceptual grouping is into 3 sets: small, medium, and large
    - The medium category includes horizontally flattened and vertically flattened
- Red and green channels of RGB color space: major interference
  - These channels are not perceived separately, but integrated into a combined perception of colors
  - Can tell that there are 4 colors, very difficult to recover the information about high and low values for each axis

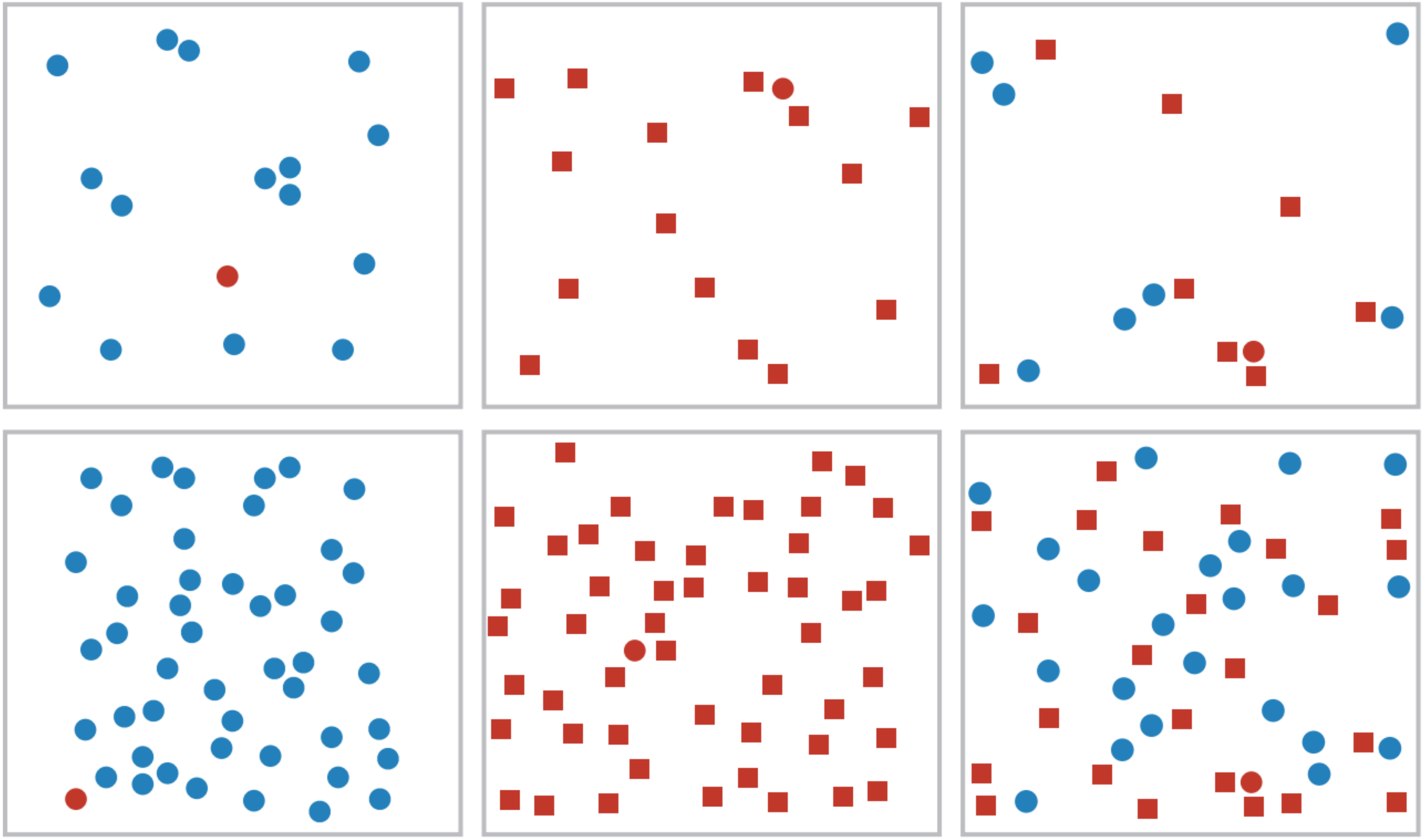
Channel Effectiveness Separability



Channel Effectiveness Popout

- **A distinct item stands out from many others immediately**
  - The time it takes to spot the different object not depends on the number of distractor objects
  - Not all-or-nothing phenomenon
    - It depends on both the channels itself and how different the target item is from its surroundings
- **Examples**
  - (1) Spotting a red object from a sea of blue ones
    - One from 15 vs. one from 50: roughly equal
  - (2) Spotting a red circle from a sea of red square
    - One from 15 vs. one from 50: roughly equal
  - (2) is slower than (1)

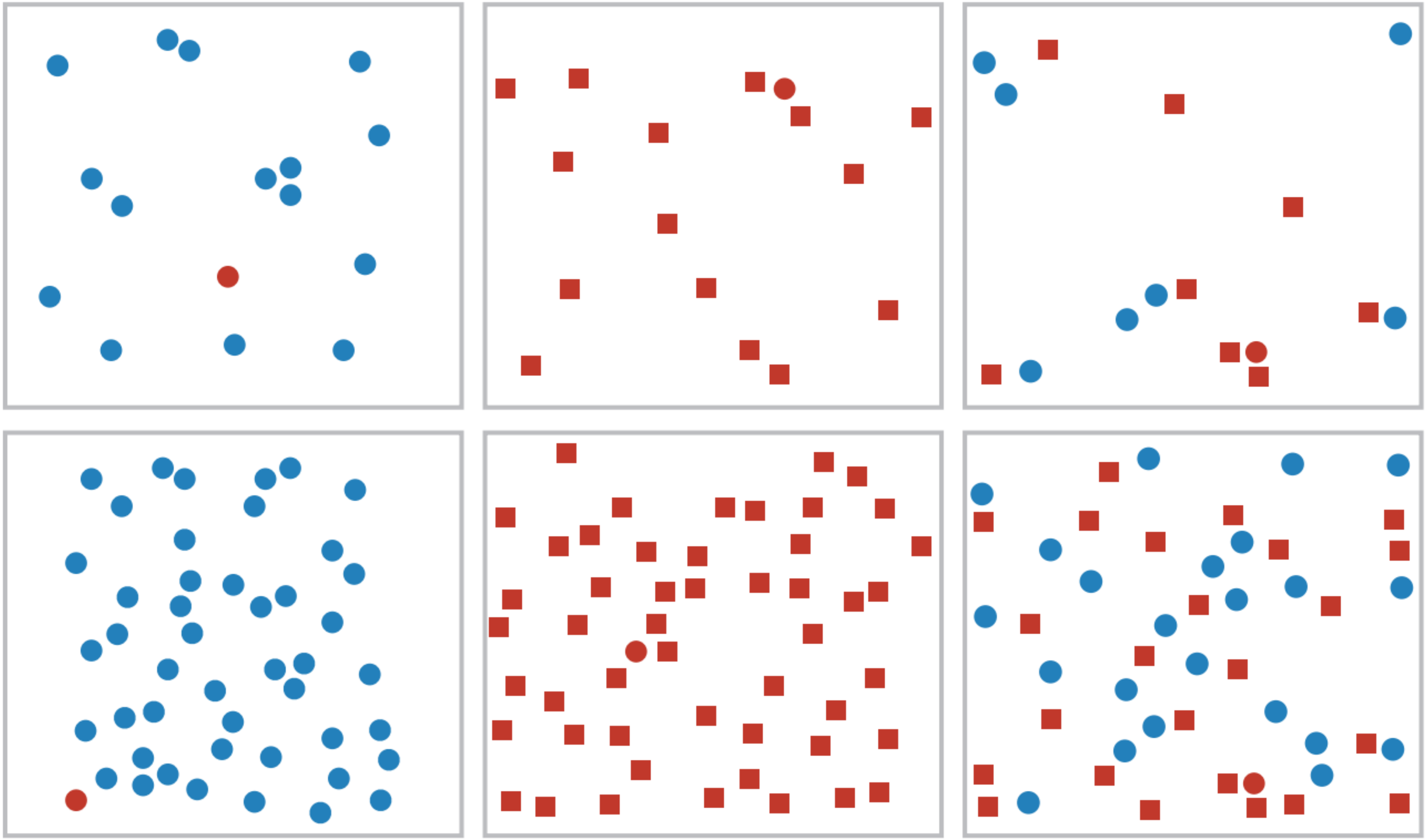
Channel Effectiveness Popout (Cont.)



Channel Effectiveness Popout

- Although many different visual channels provide popout on their own, they cannot simply be combined
- Example
  - A red circle does not popout automatically from a sea of objects that can be red or blue and circles or squares
    - (1) A small set of red squares and blue circles
    - (2) A large set of red squares and blue circles
    - (1) is much faster
      - (2) red circle can only be detected with serial search

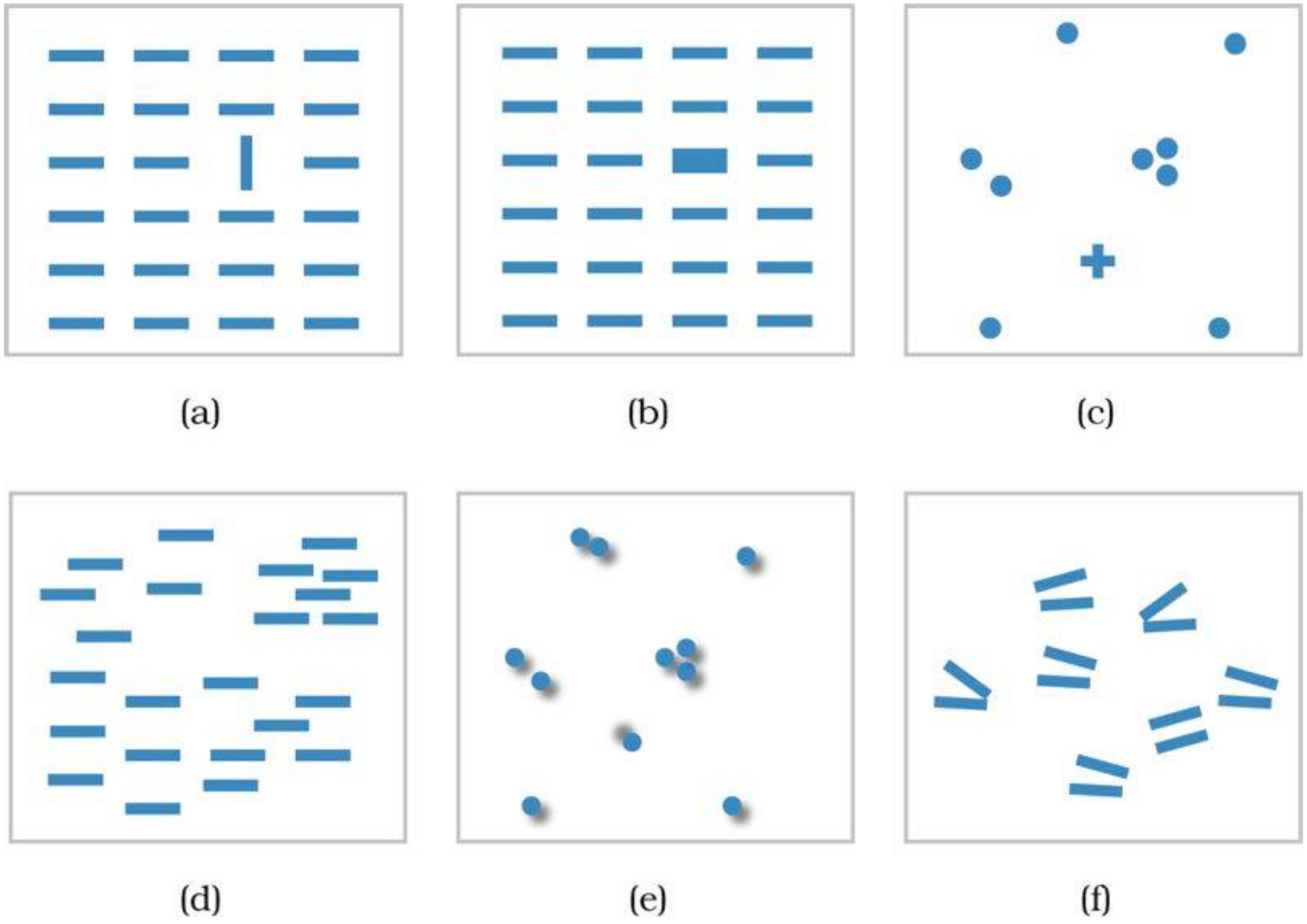
Channel Effectiveness
Popout (Cont.)



Channel Effectiveness Popout

- Most pairs of channels do not support popout, but a few pairs do
  - Space and color
  - Motion and shape
- Popout is definitely not possible with three or more channels
- Popout occurs for many channels, not just color hue and shape
  - Tilt, size, shape, proximity, shadow direction
- Several different kinds of motion support popout
  - Flicker, motion direction, motion velocity

Channel Effectiveness Popout (Cont.)



(f) Parallel line pairs do not pop out from a sea of slightly tilted distractor object pairs and can only be detected through serial search

Channel Effectiveness Grouping

- **Effect of perceptual grouping can arises from**
  - **(1st) The use of link marks**
    - **Areas of containment or lines of connection**
  - **(2nd) The use of identity channels to encode categories attributes**
    - **Encode categorical data appropriately with the identity channels**
    - **All of the items that share the same level of the categorical attribute can be perceived as a group by simply directing attention to that level selectively**
    - **Not strong as (1), but does not add additional clutter**

Channel Effectiveness Grouping

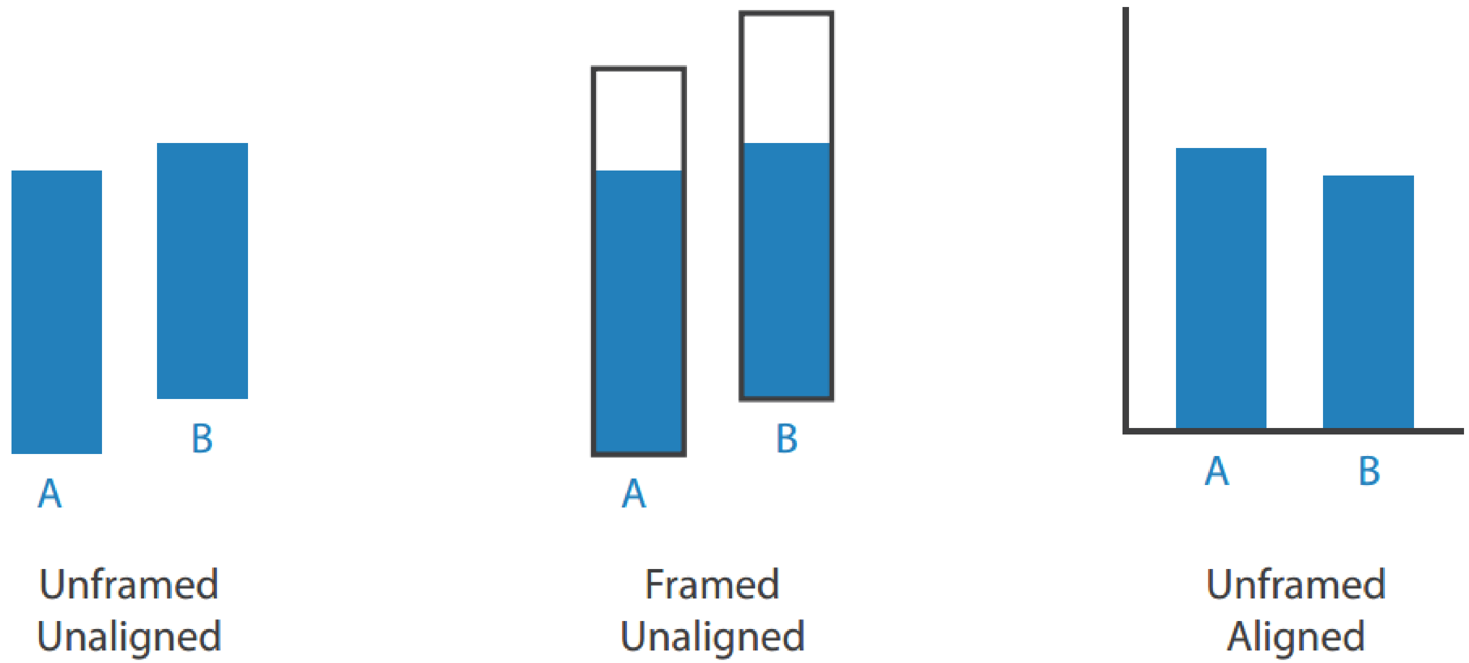
- (3rd) Proximity
  - Placing items within the same spatial region
- (4th) Similarity

- The shape and motion channel needs to be used with care
  - Not automatically create perceptual grouping
    - The shapes of a forward C and a backward C: No good
    - The shapes of a circle vs. a star: Fine
    - A set of objects moving together against a static background is a very salient cue
      - Multiple levels of motion all happening at once may overwhelm the user's capability for selective attention

Relative versus Absolute Judgments

- **Human perceptual system is fundamentally based on relative judgments, not absolute ones**
  - **The principle is known as Weber's Law**
  - **Ex. The amount of length difference we can detect is a percentage of the object's length**
- **Distinguish between relative and absolute judgments when considering questions such as the accuracy and discriminability**
  - **Ex. Position along a scale can be more accurately perceived than a pure length judgement of position w/o a scale**

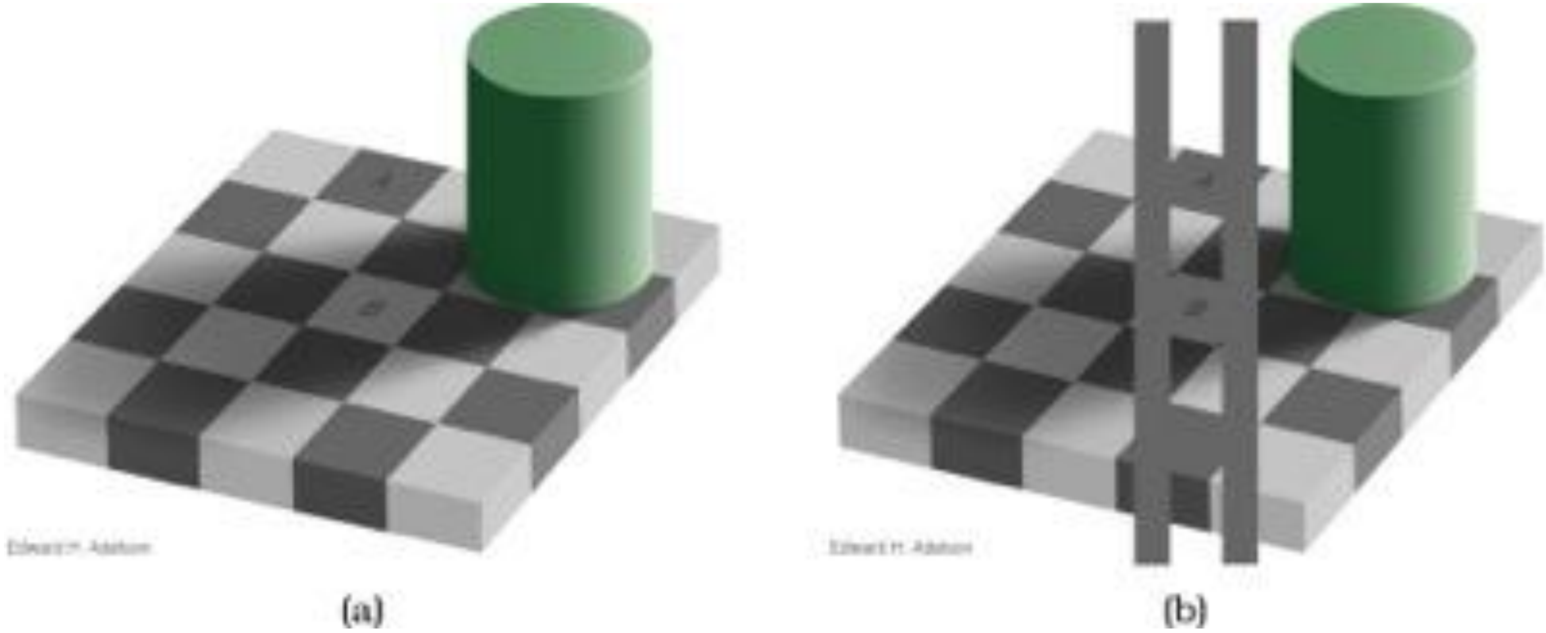
Relative versus Absolute Judgments Weber's Law



(a) The lengths of unframed, unaligned rectangles of slightly different sizes are hard to compare. (b) Adding a frame allows us to compare the very different sizes of the unfilled rectangles between the bar and frame tops. (c) Aligning the bars also makes the judgement easy.

Relative versus Absolute Judgments Luminance perception

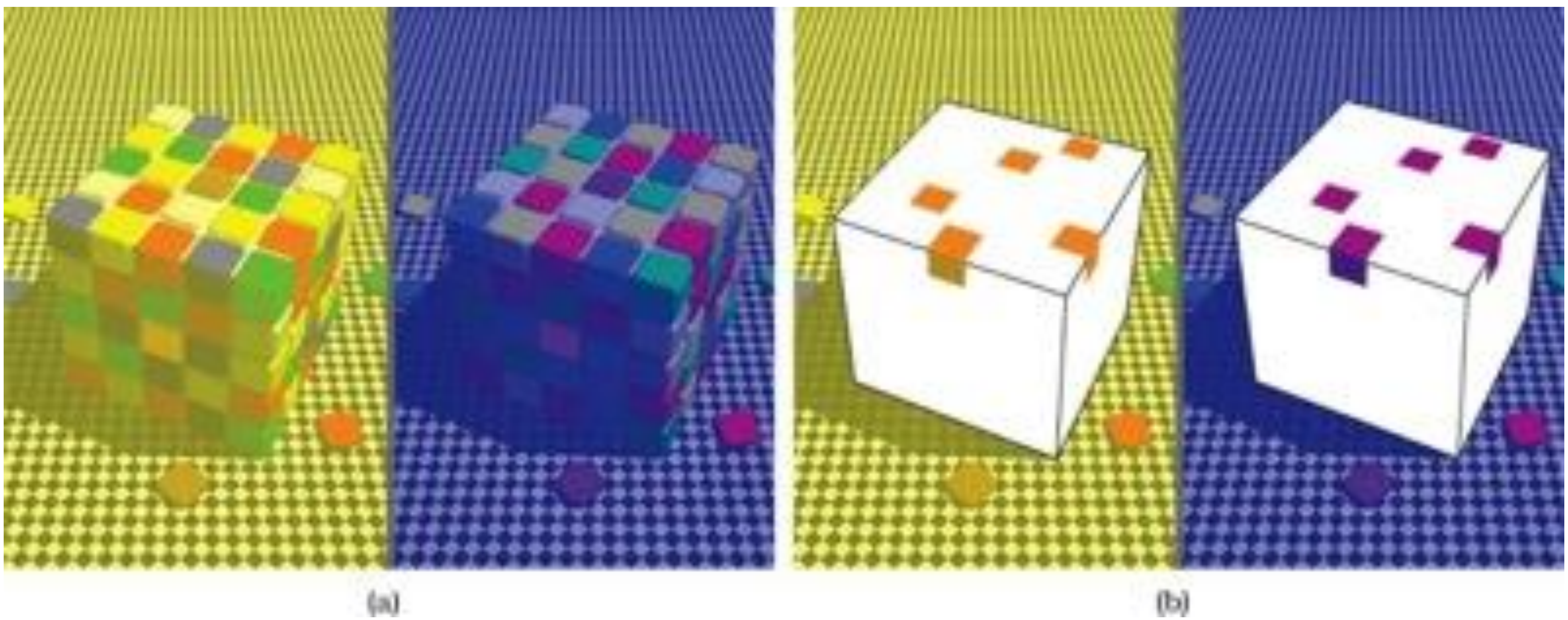
- **Luminance perception is based on relative, not absolute, judgments.**



(a) The two squares A and B appear quite different.
(b) Superimposing a gray mask on the image shows that they are in fact identical.

Color perception

- **Color perception is also relative to surrounding colors and depends on context.**



(a) Both cubes have tiles that appear to be red. (b) Masking the intervening context shows that the colors are very different: with yellow apparent lighting, they are orange; with blue apparent lighting, they are purple.